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Case alternation and length effects in lateralized word recognition: Studies of English and Hebrew

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Abstract

Effects of CaSe AlTeRnAtIoN were studied in two lateralized visual lexical decision experiments. We manipulated word length and letter case (UPPER, lower and MiXeD) in both English (Exp. 1, $N = 60$) and Hebrew (Exp. 2, $N = 60$). The previously reported visual field and word length interaction was found for upper and lower case presentation, but not for MiXeD CaSe, where both fields were affected by word length. The effects of case alternation are discussed in light of a new lateralized word recognition theory.

Keywords: Lexical decision; Hemispheres; Visual fields; Word length; Case alternation

1. Introduction

Previous lateralization studies have suggested two qualitatively different word processing modes in the cerebral hemispheres (Babkoff, Faust, & Lavidor, 1997; Bub & Lewine, 1988; Chiarello, 1988; Ellis, Young, & Anderson, 1988; Young & Ellis, 1985). In general, it has been suggested that left hemisphere (LH) processing of letters in familiar words is relatively insensitive to the number of letters in the string, whereas right hemisphere (RH) processing is affected by string length. Thus, increasing the number of letters in words presented in normal, horizontal format, caused a decline in recognition latencies in the RH, but did not affect performance in the LH (Young & Ellis, 1985). However, performance in both visual hemifields was a function of word length for invented nonwords (Young & Ellis, 1985) as well as for familiar words presented in unusual formats (vertical: Heister, 1984, or with 'steppted' letters: Ellis et al., 1988).[1] A different type of unusual format was introduced recently (Lavidor, Babkoff, & Faust, 2001), by manipulating the angle of

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[1] It was shown that the critical factor is the number of letters rather than the physical length of the letter string (Bruyer & Janlin, 1989; Young & Ellis, 1985).

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presentation of written words. This study showed that whereas the RH was affected by word length for all rotation angles, the LH was only affected by length for words rotated more than 30°.

Besner (1983), Besner and McCann (1987), and many others have used CaSe AlTeRnAtIoN in word recognition experiments to reduce configurational features of words. Allen, Wallace, and Weber (1995) reported a larger mixed case disadvantage for words than for nonwords, when targets were briefly presented, and argued that this was because familiar words have more configurational features than nonwords. Mayall and Humphreys (1996) suggested that case mixing disrupts both early letter coding and a familiarity check mechanism that is active during lexical decision (Besner, 1983). Herdman, Chernecki, and Norris (1999) concluded, for word naming tasks, that case alternation affects lexical processing in the word recognition system. Assuming that mixed case constitutes a manipulation that distorts the 'normal' format of words (like vertical or stepped words), one would expect case alternation to disrupt word recognition in the LH more than in the RH. This prediction is compatible with the lateralized two processing modes theory (Ellis et al., 1988; Young & Ellis, 1985), which claims that the LH is able to process letters in normally formatted words in parallel whereas the RH shows length sensitivity for all formats.

A different prediction might be derived, albeit indirectly, from the work of Marsolek and colleagues (Burgond & Marsolek, 1997; Marsolek, Kosslyn, & Squire, 1992; Marsolek, Schacter, & Nicholas, 1996). They argued that LH visual word recognition is abstractive in nature. Accordingly, both 'TABLE' and 'table' converge upon the same abstract representation of ⟨table⟩ that encodes the different forms of that word. RH word recognition is held by Marsolek and colleagues to be more form-specific. The idea here is that 'TABLE' and 'table' are recognized by distinct operations that map between orthographic forms and meanings in the RH. Therefore fonts and letter case are decoded mainly in the right hemisphere. As for case alternation, predictions of the abstractive/form specific theory are speculative, since such manipulation was not tested in the original studies forming the theory. However, if the specific letter case encoding is part of the right but not the left hemisphere processing, according to the theory, than the cost of mixed case should be greater for the RH. A similar argument was first presented by Fiset and Arguin (1999). Thus the prediction from the abstractive (LH) and form-specific (RH) distinction is that the disruption of the visual form of written stimuli (by using MiXeD CaSe) would have a greater effect on right than on left hemisphere processing.

Few studies have manipulated letter case in the two hemispheres. A brief report by Fiset and Arguin (1999) described the results of an experiment that used 5-letter French words in a lateralized lexical decision task. They reported a case alternation cost in response times and error rates for LH but not for RH stimuli. These results are compatible with the two processing modes model (Young & Ellis, 1985), but not with the hypothesized predictions of the abstractive-form specific model (Marsolek et al., 1992).

The goal of the present study was to explore the effects of word length and case alternation on word recognition processes in the two hemispheres, aiming to resolve the two contrasting predictions derived from the two processing modes model and the abstractive/form specific model. In two experiments, we manipulated letter case and word length in a lateralized lexical decision task using both English (Exp. 1) and Hebrew words (Exp. 2). The Hebrew script is of particular interest in laterality research because it runs from right to left rather than from left to right. The scanning direction is therefore the opposite of English. Also, initial letters are furthest from fixation in the RVF, and closest in the LVF, which is again the opposite of English. We further elucidate the advantages of using Hebrew in lateralization studies in the introduction to Experiment 2.

2. Experiment 1

In Experiment 1,[2] we employed 4-, 5-, and 6-letter English words and 3 types of letter case: upper, lower, and mixed. Based on the two processing modes model (Young & Ellis, 1985), we predicted larger letter case effects in the RVF/LH than in the LVF/RH on the grounds that the format distortion caused by case alternation would induce in the LH a more length sensitive mode of processing of the sort used for all written material presented to the RH. On the other hand, if we assume that the RH uses form-specific representations (Marsolek et al., 1992), than the right rather than the left hemisphere would be more affected by case alternation.

2.1. Method

Participants. Sixty native English-speaking undergraduates participated for course credit or £2 payment. Their ages ranged from 18 to 28 (mean age 19.4, SD 1.4). All the participants were right-handed and scored at least 70 on the Edinburgh test (Oldfield, 1971). The mean handedness score was 88. Twenty-six were males, 34 females. The participants were assigned to one of the three experimental groups: lower case, upper case, and mixed case stimuli. Thus there were 20 participants in each group. The participants in the three experimental groups did not differ significantly in their age, handedness score or gender distribution.

Stimuli. Ninety-six English content words and 96 nonwords were used as stimuli. Thirty two words had 4 letters, 32 had 5 letters, and 32 had 6 letters. The words that were used in Experiment 1 are presented in Appendix A. The three groups of different length words were matched for written frequency (Kucera & Francis, 1967), imageability, age of acquisition and number of orthographic neighbours (Quinlan, 1993, see Table 1). The nonwords were generated from another word pool, with similar frequency and orthographic neighbourhood values to the words employed, by changing one letter, such that the nonwords were pronounceable (e.g., dage, slint, and penkil). Nonwords were also made of 4, 5 and 6 letters in equal proportion. The stimuli (words and nonwords) were produced in triplicate using three types of letter case: upper, lower, and mixed such that the first letter was in upper case (MiXeD). They were presented in "Helvetica" font, size 14 points. The letters appeared white on a blue background to minimize flicker.

Experimental design. The within-subject factors were word length (4, 5 or 6-letter strings) and visual field (RVF/LVF). The between-subject factor was letter case (lower, upper or mixed). Every target stimuli was presented twice—once to each visual field. Half of the targets were first presented to the left visual field, and half to the right, and vice versa. Each within-subjects variables combination was repeated 16 times (lexicality, length, visual field and presentation order), so we had 192 word-trials (and 192 nonwords trials) for each subject in a different letter case group. The stimuli were presented in a random order with the restriction that the same combination did not appear within three successive trials.

Procedure. The practice trials started with 10 centrally presented words and nonwords in upper case, to introduce the lexical decision task. Additional 24 trials presented the 3 different letter cases used in Exp. 1. Thirty-six practice trials presented 18 new words and 18 nonwords of different lengths, half to the left and half to the right of the fixation point, in the letter case used through the experiment (upper, lower or mixed). Stimulus presentation was controlled by an IBM Pentium computer with a 586 processor, using a 17 in. SVGA display. The participants sat at a viewing

[2] Experiment 1 is an elaboration of a study reported in the TENNET 2000 (Lavidor & Ellis, 2001).

Table 1
Mean frequency, orthographic neighborhood (N), Age of Acquisition (AoA) and imageability of the words sets (Exp. 1)

	4-letter words	5-letter words	6-letter words
Mean frequency	11.1	10.5	11.1
Mean N	7.0	5.8	5.9
Mean AoA	337	329	319
Mean imageability	538	553	561

distance of 50 cm, with the head positioned on a chin rest. The importance of fixating on the focus point during the task was emphasized.

Each trial began with a + appearing in the centre of the screen. For the first trial, the + remained for 2000 ms, and disappeared when the target word was presented. The stimuli were presented for 180 ms, at a displacement of 2.5 ° to the left or to the right of a central fixation point from the centre of the word or nonword (LVF and RVF in accordance). The + reappeared after the target disappeared, and stayed for 1800 ms, during which the response was made. After the time limit of 1800 ms the + again disappeared to allow presentation of the next target word. The subject's task was to decide, as quickly and as accurately as possible, whether the stimulus was a legal English word or a nonword. Participants responded by pressing with the index fingers of their right hands on one of two available response keys, labelled 'word' and 'nonword.' For half of the participants the response 'word' was made by pressing the 'N' key of a standard QWERTY keyboard, and 'nonword' by pressing the 'V' key. For half of the participants the response keys were reversed.

2.2. Results

Response key and presentation order had neither significant effects nor interaction with the other variables, thus the data from all the 60 participants were pooled together. The results are summarized in Table 2.

Words. Two repeated measures analyses of variance were performed: One with reaction time (RT) of correct responses to words as the dependent variable and one with percent of incorrect responses for word stimuli as the dependent variable.

Response times to words. RTs to words presented in the RVF (mean = 497 ms) were significantly faster than RTs to words presented to the LVF stimuli (mean = 535 ms) [$F(1,57) = 36.1,\ p < .001$].

RTs to 4-letter words (mean = 501 ms) were significantly faster than RTs to 5-letter (mean = 516 ms), with the longest latencies being to 6-letter words

Table 2
Mean reaction times (RT) in ms and percent of correct responses to words as a function of letter case, word length, and visual field (Exp. 1)

Letter case		LVF			RVF		
		4-letter	5-letter	6-letter	4-letter	5-letter	6-letter
UPPER CASE	Mean RT	518	543	567	506	503	493
	(SD)	82	87	85	72	79	69
	% error	14	16	18	12	14	11
Lower case	Mean RT	491	522	539	476	471	481
	(SD)	82	91	79	73	82	85
	% error	11	12	13	9	7	6
MiXeD CaSe	Mean RT	521	547	568	512	532	555
	(SD)	91	108	113	90	120	112
	% error	11	13	17	13	13	18

(mean = 531 ms) [$F(2,56) = 8.9,\ p < .001$], all the post hoc analyses reported here were Scheffee with .05 significance.

The triple interaction of visual field, length and letter case was significant [$F(4,114) = 4.2,\ p < .01$]. As shown in Fig. 1, presenting the stimuli in mixed case disrupted performance for RVF (LH) but not for LVF (RH) words, as both visual fields showed length effects when letter case was mixed. The previously reported length and visual field interaction (Ellis et al., 1988) was found only for upper and lower case words. Separate analyses of the three letter case conditions showed a significant interaction between VF and length for lower case [$F(2,38) = 6.06,\ p < .01$], and upper case [$F(2,38) = 13.7,\ p < .001$], but not for mixed case [$F(2,38) = .9$, ns]. In addition, separate analyses per visual field and letter case, revealed length effects in the LVF for all letter cases [lower: $F(2,38) = 6.5,\ p < .01$; Upper: $F(2,38) = 9.0,\ p < .01$; mixed: $F(2,38) = 4.03,\ p < .05$], but a length effect in the RVF only for the mixed case [$F(2,38) = 3.87,\ p < .05$] and not for lower [$F(2,38) = 1.2$, ns] or upper case [$F(2,38) = 1.5$, ns].

Word accuracy. Responses to shorter words were significantly more accurate than to longer words, with fewer errors to 4-letter (11.4%) than to 5-letter (12.5%) and to 6-letter words (14%), [$F(2,56) = 4.08,\ p < .05$], as indicated by the Scheffee post hoc analyses. Visual field had a significant effect on accuracy [$F(1,57) = 27.7,\ p < .001$], with fewer errors in RVF (11.3%) than in LVF (13.9%).

Letter case and visual field interacted significantly [$F(2,57) = 3.69,\ p < .05$]. As shown in Fig. 2, presenting the stimuli in mixed case disrupted performance for RVF (LH) but not for LVF (RH) words. RVF performance was significantly more accurate than LVF performance for lower and upper case words, but accuracy level was similar at both visual fields for the mixed case presentations, as indicated by the post hoc analyses.

Nonwords RT. The effect of length on RT to nonwords was significant [$F(2,56) = 16.6,\ p < .001$] with faster RTs to 4-letter nonwords (mean = 545 ms) than to 5-letter (mean = 586 ms) or to 6-letter words (mean = 607 ms).

Nonwords accuracy. Visual field had a significant effect on accuracy [$F(1,57) = 5.5,\ p < .05$], with fewer errors in RVF (12.2%) than in LVF (13.7%).

No other effects were found for nonword targets.

2.3. Discussion

The findings of Experiment 1 indicate that when words are presented in mixed case rather than in either upper or lower case, standard font, performance in the

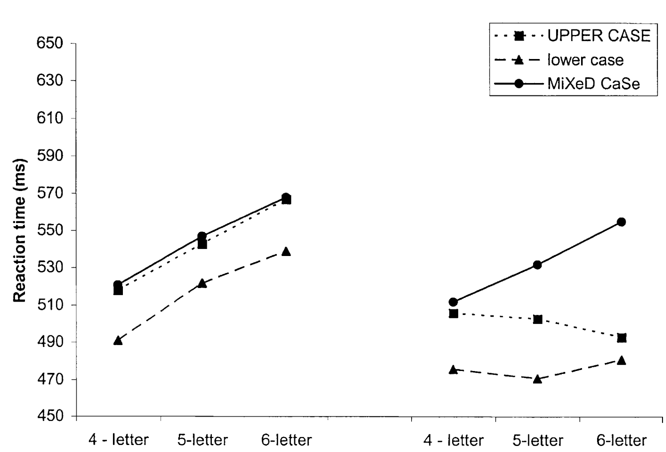

Fig. 1. Mean reaction times to words as a function of letter case, word length, and visual field (Exp. 1).

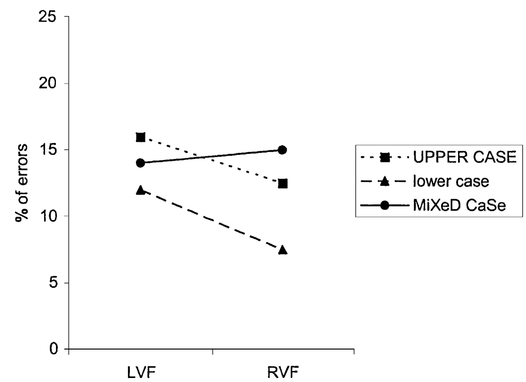

Fig. 2. Mean % of incorrect responses to words as a function of letter case and visual field (Exp. 1).

RVF/LH is significantly impaired. By contrast, the case-alternation cost is significantly smaller in the LVF/RH. For LVF/RH presented words, latencies increased with word length for each letter case, while for RVF/LH word length did not alter performance as long as the letter case is 'normal' (lower or upper case). Thus the use of mixed case is particularly costly for longer words presented to the RVF, in comparison to lower or upper cases. This is the pattern predicted by the two processing modes rather than the RH form-specific theory.

The results are in agreement with those found previously using other manipulations, namely that distorted word format, like vertical presentation (Ellis et al., 1988), rotated presentation (Babkoff et al., 1997) or stepped format (Ellis et al., 1988). Such manipulations have affected RVF/LH performance rather than LVF/RH. Thus, the distinction between length sensitive and length insensitive processing modes for words in the right and left hemispheres, respectively, is compatible with the current results as well as with those of Fiset and Arguin (1999).

Performance on nonword targets was affected by target length at both hemifields. The lack of other significant effects for the nonword stimuli implies that both hemifields were similar in processing the nonwords (as previously found by Ellis et al., 1988; Iacoboni & Zaidel, 1996). These results are in accordance with Besner's (1983), who found significant mixed case effects for word stimuli, but not for nonwords in a lexical decision task with central presentation of stimuli. According to the theory suggested by Young and Ellis (1985), nonwords are processed in a length sensitive fashion in both hemispheres, therefore the individual letter case does not inhibit the performance. Thus the lack of hemispheric interactions with length and letter case for nonwords presentation was anticipated. However, nonwords are not physically different from real words, at least not in the sense that mixed case words differ from lower case words. We will elaborate on this point in Section 4.

Experiment 2 was modelled on Experiment 1, but was conducted in Hebrew, with native speakers of Hebrew. Hebrew has attracted particular interest in the study of hemispheric asymmetry due to the fact that it is written from right to left. The Hebrew version aimed to elaborate the external validity of the mixed case and visual field interaction (French: Fiset & Arguin, 1999; English: Lavidor & Ellis, 2001).

3. Experiment 2

Before describing Exp. 2, we will summarize briefly the attributes of the Hebrew language that are particularly relevant to the hemispheric research.

The right visual field (RVF) superiority has been consistently found in lexical decision and word identification tasks for scripts like English that are printed from left to right (Barry, 1981; Bryden, Mondor, Loken, Ingleton, & Bergstron, 1990; Melamed & Zaidel, 1993). However, alternative accounts of these findings have been proposed, other than LH language superiority. Kirsner and Schwartz (1986), for example, demonstrated the superior access codability of the initial letter or letters of each word. They suggested that the first letters of a word projected to the RVF enjoy a favourable foveal viewing position. Therefore the RVF advantage often reported may not reflect the LH's dominance for language but rather is an artefact of the better acuity of the initial letters in the RVF. Obviously, the favourable foveal viewing position of the initial letters as an explanation of the RVF advantage applies only to languages that use left-to-right scripts. Thus languages such Hebrew and Arabic, with right-to-left scripts, have provided natural settings to elucidate the sources of the RVF advantage. According to the favourable foveal explanation, Arabic and Hebrew should produce a LVF word recognition and lexical decision advantage.[3] A minority of lateralization studies have revealed a LVF advantage (Melamed & Zaidel, 1993; Mishkin & Forgays, 1952), but most word recognition studies that presented Hebrew words to native or bilingual Hebrew speakers have obtained the same RVF advantage as is observed for English and other left-to-right scripts (Babkoff & Ben-Uriah, 1983; Babkoff, Ben-Uriah, & Eliashar, 1980; Babkoff & Faust, 1988; Faust, Kravetz, & Babkoff, 1993; Koriat, 1985).

The right-to-left script of Hebrew also means right-to-left reading habits. Reading habits could also produce an attention bias that might account for the RVF advantage. However, Faust et al. (1993) found the RVF advantage even when target words were preceded by six-word sentence primes, which should have directed attention to the LVF.

Hebrew also has two ways of writing letters that are roughly equivalent to the English upper and lower case. Dfus letters are square, and used mostly for printed material (books, journals and general print). Ktav letters are relatively round in shape and are used mostly for handwritten materials. In Hebrew, 11 of the 27 Ktav letters (22 letters + 5 final letters) have a physical resemblance to the corresponding Dfus letters. In English, 15 letters out of 26 have the same or very similar shapes in upper and lower case. Thus the two Hebrew writing systems can be used in the same way as we used lower, upper and mixed case in Experiment 1.

We presented words and nonwords of 3, 4 or 5 letters in DFUS, Ktav or mixed case (Dfus and Ktav) to the LVF and RVF using the lexical decision task. We predicted a length by visual field interaction for DFUS or Ktav words, but length effects in both visual fields for mixed case words.

3.1. Method

Participants. Sixty right-handed, native Hebrew speaking undergraduates participated for £3 payment. The participants were assigned to one of the three experimental groups: upper case stimuli (DFUS), lower case (Ktav) and mixed case stimuli (DFUS and KTAV). Thus there were 20 participants in each group. Their age ranged between 18 and 30 (mean age 23.6, SD 1.6). All the participants were right-handed and scored at least 85 on the Edinburgh test (Oldfield, 1971), with a mean handedness score of 95.0. Twenty-two were males, 38 females. The participants in the three experimental groups did not differ significantly in their age, handedness score or gender distribution.

[3] This is only true if initial letters carry more information about the identity of the word in Hebrew and Arabic than final letters do, an issue, which has not yet been studied.

	Stimulus	Pronunciation	Meaning
Upper case (Dfus)	אגרטל	Agartal	Vase
Mixed case	אגרטל	Agartal	Vase

Fig. 3. Examples of upper and mixed case stimuli from Exp. 2.

Stimuli. Ninety-six Hebrew concrete words and 96 nonwords were used as stimuli. All the words had only one possible pronunciation.[4] Thirty-two words had 3 letters, 32 had 4 letters and 32 had 5 letters. The three groups of words were matched for subjective frequency.[5] The mean frequency of the 3 letter words was 3.73 (on a 1–7 scale, with 1 representing very low frequency and 7 very high frequency), 3.71 for the 4-letter words and 3.81 for the 5-letter words. The nonwords were generated from another word pool by changing one letter, such that nonwords were pronounceable. Nonwords were also made of 3, 4, and 5 letters in equal proportion. The stimuli (words and nonwords) were presented in "David" font, size 14 (Dfus letters) and "Guttman Yad-Light" font, size 14 (Ktav letters). Examples of the 3 different letter cases that were used in Exp. 2 are presented in Fig. 3. The letters appeared white on a blue background to minimize flicker.

The experimental design and procedure were otherwise the same as in Exp. 1.

3.2. Results

Response key and presentation order had neither significant effects nor interaction with the other variables, thus the data from all the 60 participants were pooled together.

Words. Two repeated measures analyses of variance were performed: One with RT of correct responses to words as the dependent variable and one with percent of incorrect responses for word stimuli as the dependent variable. The results are summarized in Table 3.

Response times to words. Performance for RVF words (mean = 535 ms) was significantly faster than for LVF words (mean = 566 ms), [$F(1, 57) = 17.4$, $p < .001$]. Faster responses were found for shorter words, with faster RTs to 3-letter words (mean = 528 ms) than to 4-letter (mean = 555 ms), and the longest latencies to 5-letter words (mean = 570 ms), [$F(2, 56) = 12.8$, $p < .001$], all the post hoc analyses reported here were Scheffee with .05 significance.

The between-subject variable, letter case, had a significant effect [$F(2, 57) = 9.2$, $p < .001$] with faster RTs to Dfus words (mean = 519 ms) than to Ktav (mean = 540 ms), and the longest latencies were to mixed case words (mean = 593 ms).

[4] Another unique feature of Hebrew (which is not particularly related to hemispheric studies) is the optional use of pointing to convey vowel information. In the unpointed form of Hebrew, which is the only form used in adult's books and papers, the letters carry mostly consonantal information, with vowel information being largely implicit. Thus the same letter string in Hebrew can represent different words that are read aloud differently. For beginners in Hebrew, a system of diacritics representing the vowels is added to the script to assist reading, but later on it is omitted and experienced adults do not use it. However, lexical decision is possible in Hebrew, as reported by many studies (see, for instance, Deutsch, Frost, Pollatsek, & Rayner, 2000), if one uses nonword letter strings that do not constitute legal words even if pronounced with different diacritics.

[5] We are indebted to Ram Frost for supplying us with frequency estimates of Hebrew words collected in his laboratory in the Department of Psychology of the Hebrew University.

Table 3
Mean reaction times (RT) in ms and percent of correct responses to words as a function of letter case, word length and visual field (Exp. 2)

Letter case		LVF			RVF		
		3-letter	4-letter	5-letter	3-letter	4-letter	5-letter
UPPER (Dfus)	Mean RT	518	546	559	488	500	503
	(SD)	89	84	88	86	92	90
	% error	11	19	15	10	11	13
Lower (Ktav)	Mean RT	525	563	589	518	519	522
	(SD)	78	69	79	78	86	79
	% error	10	14	16	10	11	13
MiXeD (Dfus + Ktav)	Mean RT	571	605	624	553	600	613
	(SD)	108	122	113	91	91	125
	% error	20	29	29	16	25	27

The triple interaction of visual field, length and letter case was significant $[F(4,114) = 3.3,\ p < .01]$. As shown in Fig. 4, presenting the stimuli in mixed case disrupted performance for RVF (LH) but not for LVF (RH) words, as both visual fields showed length effects when letter case was mixed. The previously reported length and visual field interaction (Ellis et al., 1988) was found only for upper (Dfus) and lower (Ktav) case words. Both visual fields showed length effects when letter case was mixed. Separate analyses of the three letter case conditions showed a significant interaction between VF and length for upper case (Dfus) $[F(2,38) = 4.9,\ p < .05]$, and lower case (Ktav) $[F(2,38) = 3.6,\ p < .001]$, but not for mixed case $[F(2.38) = 0.9,\ \text{ns}]$. In addition, separate analyses for each visual field and letter case, revealed length effects in the LVF for all letter cases [Ktav: $F(2,38) = 4.0, p < 0.05$; Dfus: $F(2,38) = 6.1,\ p < .01$; mixed: $F(2,38) = 7.5,\ p < .01$], but a length effect in the RVF only for the mixed case $[F(2,38) = 9.2,\ p < .01]$ but not for Ktav $[F(2,38) = .2,\ \text{ns}]$ or Dfus stimuli $[F(2,38) = 1.1,\ \text{ns}]$.

Word accuracy. A main effect of word length was found $[F(2,56) = 26.8,\ p < .001]$, with fewer errors to 3-letter (12.8%) than to 4-letter (18.1%) or to 5-letter words (18.8%), as indicated by the Scheffee post hoc analyses. Visual field had a significant effect on accuracy $[F(1,57) = 9.9,\ p < .001]$, with fewer errors in RVF (15%) than in LVF (18%).

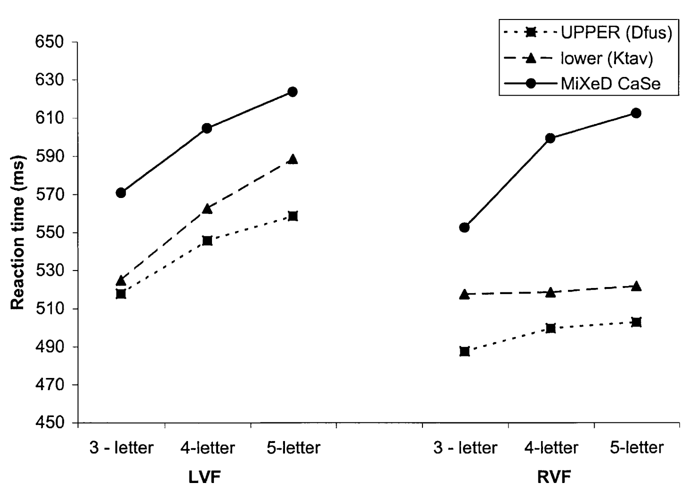

Fig. 4. Mean reaction times to words as a function of letter case, word length and visual field (Exp. 2).

Nonwords RT. Nonword length was significant [$F(2,56) = 5.63$, $p < .05$] with faster RTs to 3-letter nonwords (mean = 622 ms) than to 4-letter nonwords (mean = 638 ms), and latencies to 5-letter nonwords were the slowest (mean = 657 ms).

Nonword accuracy. No significant effects or interactions were found.

3.3. Discussion

The main result of the Exp. 2 is that with case alternated presentation, reaction times for words in both visual hemifields were affected by word length, whereas for 'normal' word formats (e.g., same case), word length affected LVF but not RVF performance. The results are in accordance with the English version of the same experiment (Exp. 1). The significant interaction found between word length and visual field (for the same letter case) implies that the RVF advantage often reported is not due to scanning habits or better foveal acuity for the initial letters, since the stimuli were presented in a right-to-left language. The ability of the LH to perceive normally formatted familiar words in a more or less parallel manner is not language- or script-dependent. The results are also in accordance with previous results reported for central presentation (Koriat & Norman, 1985, 1989), where length sensitivity was found only for rotated words (distorted format) but not for horizontal, normally presented words.

The RVF advantage for the same case presentation in Hebrew is in line with most previous Hebrew lateralization studies (Faust et al., 1993; Koriat, 1985). Thus the RVF advantage is not due to scanning habits but reflects hemispheric differences (for right-handed participants). Despite the different scanning patterns of Hebrew and English, recognition of familiar words in familiar formats is length-sensitive in the LVF in Hebrew but not in the RVF. The difference in length sensitivity between the two visual fields (and therefore the two hemispheres) appears to reflect some hard-wired differences in processing modes between the hemispheres that is not affected by the scanning direction of the script one learns in childhood.

4. General discussion

The main result of the reported experiments is that with case alternated presentation, reaction times for words in both visual hemifields were affected by word length, whereas for 'normal' word formats (e.g., same case), word length affected LVF but not RVF performance. The current results are not easily accommodated by the RH form-specific theory (Marsolek et al., 1992) that would predict larger mixed case effects in the RH. Both visual fields were affected by the mixed case words, and the LH showed a greater case alternation cost.

On the other hand, Experiments 1 and 2, together with previous results (Fiset & Arguin, 1999; Lavidor & Ellis, 2001), provide support for the notion of the two different processing modes available in the hemispheres (Bub & Lewine, 1988; Ellis et al., 1988; Young & Ellis, 1985). The more efficient, parallel processing mode of the LH is activated only for words in a standard format. Distorted words, such as we showed here by using mixed case letters, are processed in a more serial mode, which is also the typical processing mode in the RH. The seriality of the process was demonstrated by the length effects in LVF for all letter cases, and for RVF in mixed case presentations. The length sensitivity is probably not due to serial, right-to-left processing, but reflects increasingly poor performance for letters in the middle of strings as length increases. The causes of that could be ends-in scanning (Jordan, Patching, & Milner, 2000) or increasing lateral inhibition with increasing number of letters (Estes, 1972).

The lack of mixed case effects for the nonwords, both in English (Exp. 1) and Hebrew (Exp. 2) is consistent with the findings of Besner (1983) who demonstrated stronger case alternation effects for words than for nonwords in a lexical decision task. He proposed that there are two types of word recognition, one requiring the unique specification of a word, the other is merely the assertion of familiarity. The latter is said to rely on a familiarity discrimination mechanism (FDM), which takes the figural pattern of a word as input and outputs a "crude estimate of the stimulus' visual familiarity" (Besner, 1983, p. 432). Lexical decision latencies can reflect this second type of recognition. Because case alternation disrupts the overall word shape, it is assumed to prevent the effective use of FDM. According to Besner (1983), since nonwords are by definition less familiar than words, case alternation is less destructive to nonwords.

However, nonwords are not physically different from real words, at least not in the sense that mixed case words differ from lower case words. In light of the orthographic similarity of legal nonwords and words, the processing differences cannot be related to the FDM. A different explanation for the greater mixed case costs for words than for nonwords (in central, brief presentation) was suggested by Allen et al. (1995) with the holistically biased hybrid model of visual word processing. The main assumption of the model is that the orthographic pathway is further divided into word-level, syllable level and letter-level routes, where all the channels are involved in 'horse race' to the central processor (which selects the winning input code in order to complete the task at hand). In a lexical decision task, the word-level input channel would become the functional processing unit for words presented in a consistent letter case, but not for nonwords (in a brief exposure) since their holistic familiarity value is too low to activate the word-level channel. Thus nonwords with same case font will be handled by the letter-level input processor. As for letter strings in mixed case, they will be processed using superposed letter-level codes, resulting in a relatively small mixed case disadvantage for nonwords, as the letter-level is their typical route, but greater disadvantage for words as the word-level route is not activated. The larger mixed case disadvantages for words than for nonwords, as predicted by the model, was supported in Allen et al.'s study (1995).

A lateralized version of the holistically biased hybrid model would emphasize the word-level processing in the left hemisphere, based on the well-known LH superiority over the right hemisphere in linguistic tasks. We suggest that real-words, in standard format (same case and not mixed case letters, as shown in the current study) activate quite rapidly the word-level channel, which has a top-down support from the mental lexicon. The top-down support is mainly a LH process, and is activated only for familiar words. By definition, nonwords (mixed case or not) cannot use the, top-down support, thus their processing is slower compared to words. Thus nonwords and mixed case words are processed in the letter-level channel.

It is possible that both routes exist in the two hemispheres, but the hemispheres differ in the activity levels of the processing channels, with the word-level route more efficient in the LH than in the RH. Evidence for the greater RVF top-down support, compared to LVF, was reported in previous word superiority effect (WSE) studies, where Krueger (1975) found a larger WSE in RVF than in the LVF.

In the current study we employed a single task (lexical decision) in both experiments. Previous literature suggested that the mixed case effects may be task specific, as Mayall and Humphreys (1996) have shown that lexical decision was more disrupted by case mixing than was word naming. The straight forward interpretation for this is that case mixing disrupts early letter coding, however semantic and syntactic processing continues normally following the disrupted production of abstract letter codes. It is possible therefore that the two processing modes theory we suggest is valid only at the early coding stages in the two hemispheres. Later processing stages may reveal other quantitative or qualitative hemispheric differences (or similarities). Such a possibility may account for the differences between our findings and those reported by Hellige and colleagues about nonwords processing in the two hemispheres (Hellige, Cowin, Eng, & Sergent, 1991; Hellige, Cowin, & Eng, 1995; Hellige & Marks, 2001). Hellige and colleagues, presenting nonwords, have shown that for tasks that require explicit letter string identification, like spelling or pronunciation, the RVF/LH is more parallel than LVF/RH processing. In contrast, the current findings show that nonword processing in a lexical decision task is affected by string length in both hemispheres. However the different tasks used by us and Hellige may suggest that hemispheric processing modes differences are dynamic and may change along the different processing stages. Further experiments are required in order to establish the hemispheric processing differences along the timeline and depth of linguistic processing.

Recently Chiarello (2002) have suggested a new interpretation to the abstractive/form-specific model (Marsolek et al., 1992). She suggested that words received by the LH very rapidly achieve deeper or more abstract encoding, while words received by the RH maintain and perhaps even amplify early encoding even when deeper level codes become available. Using her interpretation, it may be that words presented to the LH achieve a deeper encoding sooner than RH stimuli, but only if their format is standard. Distorted words (made of mixed case letters, for example) linger longer in the early encoding stages. This delayed stage is the routine process in the RH for all written stimuli. Thus for such words, the pre-lexical processing stages are similar in both hemispheres. Hence, we got the same significant effect for mixed case words in both visual fields. Currently, this interpretation is speculative, supported mainly by indirect evidence. For instance, support for the faster transition to word-level processing in the LH may be derived from the finding of faster activation in the LH than in the RH for words in standard format (Collins, 1999; Koivisto, 1997; Koivisto, 1998). Further experiments are required to test this potentially interesting theory that may link Marsolek's theory with the theory of the two processing modes (Ellis et al., 1988).

In summary, we have shown hemispheric differences in the processing of letter strings. Letter strings can be processed in a length sensitive pattern, where more letters in the string affect performance, or in a length insensitive pattern, where number of letters in the string does not alter performance. Previous studies, together with the current results, have revealed that the length sensitive processing mode is found in the LVF for familiar words in any format and for familiar words in RVF in nonstandard formats. The only condition in which insensitive length processing was found was when familiar words were presented to RVF in normal format.

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Appendix A. Stimuli for Experiment 1

4-letter words	5-letter words	6-letter words
ACRE	APPLE	BANKER
ARCH	BLADE	BARREL
AUNT	BLUSH	BORDER
BABE	BROOK	BUBBLE
BRIM	CANAL	BUFFER

Appendix A. (*continued*)

4-letter words	5-letter words	6-letter words
CHOP	CHEEK	BUTTER
CRAB	COACH	BUTTON
CROW	CORAL	CHERRY
CUBE	DIRGE	COPPER
DISC	DITCH	FIDDLE
DUSK	DOUGH	HALTER
EARL	FLOCK	HAMMER
ECHO	GIANT	HUNGER
FORK	GLOBE	HUNTER
GASP	GRIEF	INSECT
HOWL	JUICE	KETTLE
JUMP	LOBBY	KITTEN
KICK	ONION	MARBLE
LENS	PASTE	PEPPER
PLUG	POUGH	PILLOW
PREY	RANCH	RABBIT
ROAR	SCOUT	RATTLE
SAND	SHIRT	RUBBER
SHED	STAIN	SCREAM
SLIT	STEAM	SHIVER
SOAP	STOOL	SHOWER
SWIM	STOVE	SINGER
TOMB	STRAW	STRIDE
TRIM	STUMP	TAILOR
VASE	THUMB	TICKET
VETO	TOWER	TUMBLE
WEEP	WITCH	WIGGLE

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